National Defence Défense nationale

Canada

[redacted]

19960201 045

Defence and Civil
INSTITUTE OF ENVIRONMENTAL MEDICINE
INSTITUT DE MEDECINE ENVIRONNEMENTALE
pour la défense

1133 Sheppard Avenue West, PO Box 2000, North York, Ontario, Canada M3M 3B9
Tel. (416) 635-2000 Fax. (416) 635-2104

October 1995 DCIEM No. 95-32

THE EFFECT OF MONITOR TYPE AND DISPLAY ORIENTATION ON THE DETECTION OF LINES ON A SIMULATED PASSIVE SONAR DISPLAY

S. M. McFadden
B. L. Giesbrecht
K. C. Kalmbach

Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West, P.O. Box 2000
North York, Ontario
Canada M3M 3B9

ABSTRACT

With current sonar technology the operator must handle large quantities of data. The primary medium for displaying these data is the CRT. Because of the limited space available on the CRT, the operator must scan multiple pages of data rapidly if he or she is to monitor all of the information. Thus, signal visibility is critical. To ensure good visibility, it is necessary to understand the impact of display characteristics on the detectability of signals on a display. This study examined two factors that could influence the detection of lines on a frequency-time-intensity (FTI) display. The first was type of monitor - multichrome or monochrome. Current systems use a monochrome monitor because its resolution is believed to be superior to a multichrome monitor. The second was orientation of the signals relative to the orientation of the CRT raster. Currently, the signals on an FTI display are perpendicular to the CRT raster. The study examined the advantage of having signal lines on the FTI display fall along the scan lines of the CRT. Two experiments were carried out to assess the effect of these factors on the detection of signals of varying strength presented on a simulated FTI display. Performance was similar on the monochrome and multichrome monitors. However, there was a slight advantage, about 1 dB, to using a display format in which the signals fell along the scan lines of the CRT. This improvement increased to 2 dB for signals that were separated by one pixel from a stronger signal. It was concluded that detection was not impaired on a multichrome display and that there could be an advantage to designing the interface for a passive sonar display so that the signals fall along the scan lines of the CRT.

EXECUTIVE SUMMARY

With current sonar technology the operator must handle large quantities of data. The primary medium for displaying these data is the CRT. Because of the limited space available on the CRT, the operator must scan multiple pages of data rapidly if he or she is to monitor all of the information. Thus, signal visibility is critical. To ensure good visibility, it is necessary to understand the impact of display characteristics on the detectability of signals on a display. Thus, DCIEM was tasked to investigate two factors that were believed to influence the detection of signal lines on a frequency-time-intensity (FTI) display. The first of these was type of monitor - multichrome (multiple phosphors or guns) versus monochrome (single phosphor). Current sonar systems in the Canadian Forces use a single phosphor monitor because its resolution is believed to be superior to a multichrome monitor. However, there is considerable pressure to switch to a multichrome monitor for consistency with other computer-based systems and to take advantage of the benefits associated with colour coding. The second factor was the orientation of the signals relative to the orientation of the raster on the CRT. For consistency with paper FTI displays, frequency is plotted along the x axis and time along the y axis on a CRT. One consequence of this decision is that the signals are perpendicular to the scan lines of a CRT. It would seem useful to capitalize on the inherent line structure in the CRT when presenting images, such as an FTI display, that contain line patterns that are predominantly in one direction.

Two experiments were carried out to assess the effect of these factors on the detection of signals of varying strength presented on a simulated FTI display. Subjects were presented with a set of static FTI displays each containing between six and ten lines one pixel wide extending across all time bins and were asked to indicate the location of each of the lines that they could see. The first experiment examined detection performance on the two types of monitors using the standard FTI format. Performance was similar on the monochrome and multichrome monitors. The second experiment compared detection on the monochrome monitor when the FTI displays were presented in the standard format, when the time and frequency axes were reverse, and when the monitor was rotated so that the axes appeared in the standard format, but the time axis was parallel to the scan lines. There was a slight advantage, about 1 dB, to using a display format in which the signals fell along the scan lines of the CRT. This improvement increased to 2 dB for signals lines that were separated by one pixel from a stronger signal line.

It was concluded that detection was not impaired on a multichrome display and that there could be an advantage to designing the interface for a passive sonar display so that the signal lines fall along the scan lines of the CRT. It was recommended that the advantages of using a multichrome monitor for displaying passive sonar data be investigated and that the advantage of having the signal lines on a FTI display fall along the scan lines of the CRT be tested on a multichrome monitor and under more realistic conditions.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Background

The most common method for presenting passive sonar information visually is the frequency-time-intensity (FTI) display. The FTI display shows the output of 'x' narrow-band filters over 'y' previous time periods. The average energy in one of the x frequency bands (or bins) over one of the y time periods is shown by brightness (on an emissive display) or darkness on a paper display. The energy in all time bins for a single frequency bin appears as a single, variable intensity, line. Targets appear as sets of lines against a noisy background. Initially, the medium for the visual display of passive sonar information was paper. Frequency was plotted along the x axis and time along the y axis. Since the paper display was continuous, the operator often had extremely long histories available. These enhanced the visibility of targets because detectability is a function of line length(2).

Improvements in signal processing algorithms and computing power have resulted in a considerable increase in the amount of information that can be extracted from sensor systems. Different sectors of the ocean can be monitored separately and a wide range of frequency resolutions, update rates, and temporal resolutions can be made available to the operator. The paper display is totally inadequate for displaying this additional information; a separate display would be required for each section of the ocean. To redisplay existing data at a new resolution would require a considerable delay. Thus, the increase in computing power was accompanied by a switch from paper to electronic displays. The electronic display provides greater flexibility in terms of how the information can be displayed at any point in time. As a result of increased processing power, the operator can adjust frequency and temporal resolution almost instantaneously.

However, the amount of information that can be displayed simultaneously on an electronic display is limited by the size and resolution of the screen. To monitor all of the information, the operator must scan multiple pages of data rapidly. Under such conditions, the visibility of signals is critical. However, the long histories found on paper displays are not possible. Alternate methods are required to maintain and increase the visibility of signals. A simple method would be to increase line width and a study by Moulden and Kingdom(3) did find that detection increased as the number of pixels used to display each frequency bin increased. However, increasing the number of pixels used to display each frequency bin means that frequency resolution or frequency range must be reduced. McFadden et al (4). found that reducing frequency resolution by a factor of two reduced detectability by 1.5 dB. There are alternate ways of improving the visibility of signals. One possibility is to increase the number of quantization levels used. Both McFadden and Swanston(5) and Moulden and Kingdom(6) found that detection improved as the number of quantization levels was increased from two up to eight.

The requirement for good visibility of signals makes it important to understand the impact of display characteristics on detectability. Thus, DCIEM was tasked(1) to investigate two factors that were believed to influence the detection of target signals on a CRT screen. The first of these was type of monitor - multichrome (multiple phosphors or guns) versus monochrome (single phosphor). The second was the orientation of the signals relative to the orientation of the raster on the CRT.

Currently, passive sonar systems in the CF use monochrome monitors. The amount of information presented on an FTI display is usually a function of the display addressability. Addressability is a function of the display controller and refers to the number of specific points or x,y coordinates on the screen that can be selected. Whether each of those points is visible depends on the resolution of the screen. Resolution is usually defined as the width of a spot or pixel on the CRT when its luminance falls to 50% of maximum(7). With single phosphor CRTs, this width is a function of several factors. However, it is theoretically possible to make resolution infinitely high, but if resolution exceeds addressability, black lines will be visible between successive lines of pixels. As addressability exceeds resolution, it becomes increasingly difficult to discriminate two lines separated by a single line of pixels. This is especially true if the luminance difference between the two lines of interest and the intervening pixels is relatively small, which is the case with FTI displays. Ideally, the resolution to addressability ratio (RAR) should be one. This is usually achievable on monochrome CRTs.

With shadow-mask CRTs (the most commonly used multichrome CRT), resolution is limited by the pitch of the shadow mask (distance in millimetres between vertically adjacent mask-hole centres). Usually a minimum line width of 1.1 to 1.2 the mask pitch is adequate(7). This is lower than the resolution that can be achieved on a monochrome screen and the number of addressable points will have to be lower as well to achieve an RAR of one. Otherwise, one may not be able to discriminate pairs of lines separated by a single line of pixels on the multichrome screen.

To present as much information as possible on the screen at one time, the largest number of pixels possible are addressed on a monitor used in a passive sonar system. This can lead to an RAR of substantially greater than one if a multichrome monitor is used. The impact of this high RAR is not clear. Operators evaluating the CANTASS ADM with monochrome and multichrome monitors that had the same number of pixels and lines per inch, have consistently preferred the monochrome monitor. On the other hand, Volkov (8) concluded that detection of signals on an FTI display was not significantly better on a monochrome monitor than a multichrome. The addressability of his monitors was 1024 lines by 1280 pixels and the pitch of the shadow mask on the multichrome monitor was 0.32 mm. He compared detection of signals on a sonar display presented on a monochrome monitor with a green phosphor and a multichrome monitor using the green or red gun to display the data. There was a small but significant advantage for the monochrome monitor over the multichrome monitor using the green phosphor. This advantage was found primarily with signals that did not vary in frequency. When the frequency of the signals varied with time, there was no difference in detection performance. Moreover, there was no difference between the red phosphor on the multichrome monitor and the monochrome monitor.

The study by Volkov did not systematically investigate the detectability of two signals separated by a single line of pixels. It is important that an operator be able to discriminate a doublet from a single line signal. The presence of doublets can be indicative of a particular class of target. In other cases, two signals close together can indicate the presence of more than one target. In the latter case, one of the signals may be fainter than the other. If the stronger signal masks the fainter signal then the operator may fail to detect the second target. As well, using the green gun to display sonar data on a multichrome monitor may not be desirable. The main advantage of going to a multichrome monitor is to allow colour

coding of information on the display. The colour appearance of symbols will be modified if they are presented against a saturated green background (9). To optimize colour discrimination, it is preferable to map intensity on to different achromatic brightness levels on an FTI display.

The second parameter that was investigated was display orientation. For consistency with paper FTI displays, frequency is plotted along the x axis and time along the y axis on a CRT. One consequence of this decision is that the signals are perpendicular to the scan lines of a CRT. In a raster scanned CRT (the type used most consistently for sonar displays), the electron beam scans horizontally across the field, is deflected back at the end of the line, and scans across the next portion of the screen. This process is repeated until the entire screen has been scanned. The image on the screen is formed by turning on the electron beam the appropriate amount at prespecified points across the screen surface. It would seem useful to capitalize on this inherent line structure in the CRT when presenting images that contain line patterns that are predominantly in one direction. For example, contrast sensitivity assessment systems that present vertical sinewave patterns on a CRT usually use a monitor that has been rotated 90 degrees so that the grating patterns are parallel to the raster.

There are two possible ways of presenting the FTI display so that signals fall along the scan lines of the CRT. The simplest is to display frequency along the y axis and time along the x axis. However, this could necessitate considerable retraining of the sonar operators. Although operators are trained to classify targets analytically, successful classification usually involves matching the pattern on the screen with an internal template that has been built up as a result of extensive experience with similar patterns. Changing the orientation of the FTI display could reduce the effectiveness of this pattern matching process in the short term. The second method would be to rotate the monitor so that the scan lines are vertical. Signals would fall along the scan lines when the the data are presented in the standard format on this rotated monitor.

Current Study

Two experiments were carried out in support of the tasking. The first compared detection of signals on a simulated sonar display presented on a single phosphor, greyscale monitor with detection on a multichrome monitor in which signal intensity was mapped onto different grey levels. The second study compared detection when the FTI displays were presented in the standard format, when the time and frequency axes were reverse, and when the monitor was rotated so that the axes appeared in the standard format, but the time axis was parallel to the scan lines.

Performance was compared using a detection task in which subjects were required to locate signals of varying intensities on a simulated FTI display. A schematic of the stimulus configurations in the three orientations is shown in Figure 1. On each trial, signals were presented at six different locations on the display. Twenty percent of the signals were doublets, defined as a two signals differing in frequency by 1 or 2 Hz. The intensity of each signal in the pair was randomly selected. Subjects had to click on both signals. Ten percent of the signals were zigzag rather than straight to simulate signals that varied in frequency over time.

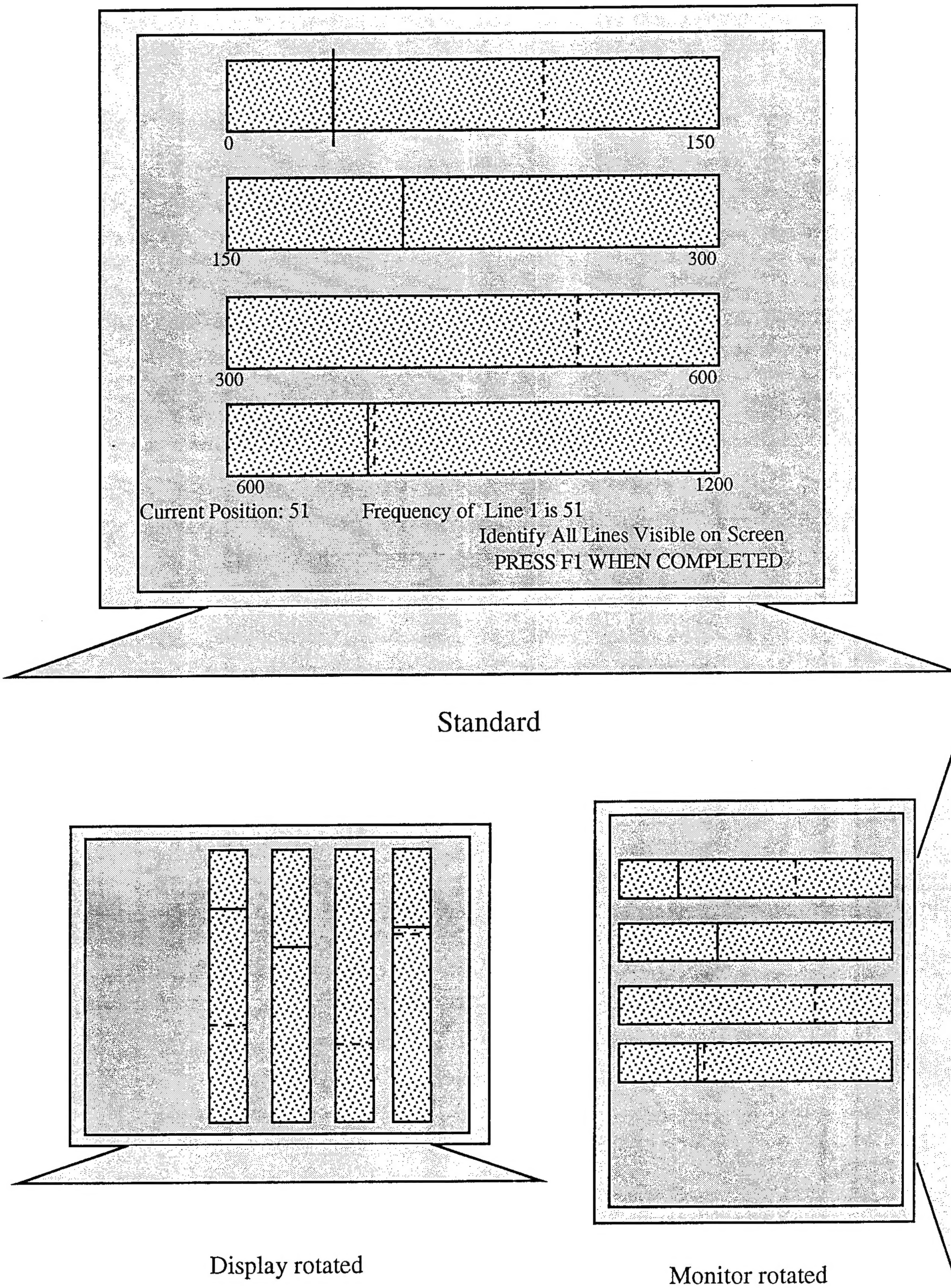

Figure 1: Schematic of the stimulus configuration for the standard format and the orientation of the display and the monitors for all three orientations.

METHOD

Subjects

A total of 21 observers, 10 males and 11 females, participated in the experiments. They ranged in age from 21 to 63 (mean = 31.6) and had normal or corrected-to-normal vision based on self-report, as well as a measure of visual acuity (Regan Chart) and a measure of contrast sensitivity (Nicolet CS2000 System). All subjects were naive to the task, but they were given a complete explanation of the study and the task before giving their consent. They were recruited from DCIEM personnel and from nearby universities and were compensated for their participation according to federal government guidelines.

Apparatus

The Sonar Display Simulation System was controlled with a Northern Micro personal computer with an 80486 processor and an ATI Graphics Ultra Pro video card. The simulation was displayed on either a 51 cm Nanao multichrome monitor or a 53 cm Nanao greyscale monitor. A special apparatus was constructed to allow the greyscale monitor to be easily rotated 90 degrees. As a result, the centre of the screen was 43 cm above the table top. The multichrome monitor was raised the same distance for consistency.

The addressability of both monitors was set to 1024 pixels by 764 lines and the active area of the screen was equalized between the monitors such that each pixel had a nominal visual angle of 2.3 min. of arc at a viewing distance of approximately 53 cm. The x,y chromaticity coordinates were 0.348, 0.400 for the greyscale monitor and 0.333, 0.395 for the multichrome monitor[1] at a luminance of 44 cd/m^2. Interaction with the screen was carried out using a mouse and special function keys. Subjects used the mouse to position a cursor over a possible signal and then clicked the left button on the mouse to record their response. A function key was pressed to indicate the end of a trial.

The two monitors were characterized, using a Minolta CS-100 hand-held colorimeter fixed to a tripod, by measuring the output at every fourth DAC (digital to analog) or voltage input level between 0 and 64 (the maximum DAC value). Each level was measured by displaying a block of pixels at the desired DAC value. In the case of the multichrome monitor, the measurements were made with the identical DAC values applied to all three phosphors. Luminance was plotted as a function of DAC value and a curve fitted to the data. The curves were used to select the DAC values on each display that would produce the same luminances and that would result in each successive luminance level differing from the previous by at least a factor of two. These luminance levels were checked at regular intervals throughout the experiment. If the monitors started to drift, they were characterized again and new DAC values were selected that would produce the original luminances.

[1]These were the chromaticity coordinates for the multichrome screen when the same DAC (Digital to Analog Conversion) values were applied to each gun.

Stimulus configuration

A schematic of the the stimulus configuration for the standard condition and the other orientations is shown in Figure 1. Only the standard configuration was used on the multichrome monitor. In the standard (multichrome and monochrome) and rotated monitor conditions, frequency was displayed along the horizontal axis, time along the vertical axis, and intensity was mapped on to the luminance of the pixels, such that the more intense the energy in a given frequency-time bin the higher the pixel luminance. In the display rotated condition, the axes for frequency and time were reversed. Each of the four bands in the displays spanned 720 pixels (25.3 cm) by 112 pixels (4 cm), with a 50 pixel separation between the bands. At the nominal viewing distance of 53 cm, the visual angle subtended by the four bands was 25.5° of arc horizontally (vertically in the display rotated condition) and 21.6° of arc vertically (horizontally in the display rotated condition). The frequency range displayed was 1200 Hz, with 0-155 Hz on the top band, 150-305 Hz on the second, 300-611 Hz on the third, and 576-1200 Hz on the fourth band. There was a small frequency overlap at the ends of the bands to facilitate the detection of signals that might appear in those areas. Along each band were scale markers (not shown on the schematic) placed at 25 Hz intervals on the two lower frequency bands and at 50 Hz intervals on the two higher frequency bands.

Signals were presented as lines one pixel wide and 112 long that replaced the background noise. The cursor was also displayed as a line one pixel in width and 120 pixels in length, so that it extended four pixels either side of each band. At the bottom of the screen in the standard configuration and the left hand side of the screen in the display rotated configuration, the subject was given information about the current location of the cursor (in Hz), the number of responses made so far in the current trial, and the last frequency clicked on. The instructions 'Identify All Lines Visible on Screen' and 'PRESS F1 WHEN COMPLETED' were also presented in this area. The alphanumerics were displayed at a luminance of 2.5 cd/m^2 and the cursor was displayed at a luminance of 11 cd/m^2.

The initial noise background was generated and stored in an image file that the controlling software read in at the beginning of a run. The noise distribution of the first band was divided into four sections at the start of a run and then randomly recombined to create four new bands for every trial. This was done because regeneration of the complete display required too much time and computer memory to be done within the application.

Signal and noise intensity were mapped onto eight different luminance levels (Table 1). Eight levels were used because past research has found that increasing the number of luminance levels beyond eight does not significantly improve detection performance(5, 6). The sets of luminances for the two monitors were nominally the same. However, as shown in Table 1, there was some variation in the actual luminances that were achieved. This was due in part to day to day variation and in part to the fact that only 64 DAC levels were available.

Table 1: Average pixel luminances of the monochrome and multichrome monitors[2].

Monitor	Luminance (cd/m^2)							
	1	2	3	4	5	6	7	8
Monochrome	<0.01	0.02	0.05	0.10	0.6	2.5	11.2	44.3
Multichrome	<0.01	0.03	0.07	0.12	0.6	2.5	11.4	44.2

The probability that a specific level was assigned to a specific pixel was determined using the following equation for the binomial rule (Equation 1). In this equation, p is the mean of the distribution (0-1), i is the specified level (1-8), N is one less than the number of levels being used (in this case 7), and $r = i - 1$. To create a Gaussian noise background, p was set equal to 0.5.

$$P(i) = \frac{N!}{r!(N-r)!} \times p^r (1-p)^{N-r} \tag{1}$$

The mean luminance of the noise background was calculated using equation 2(6). In this equation, p_i is the probability that the luminance level L_i will be assigned to a pixel. Using this equation, it was calculated that the average display luminance was 1.6 cd/m^2 for both monitors. Similar levels were found when the noise backgrounds were measured with the Minolta CS100 colorimeter.

$$\bar{L} = \sum_{i=1}^{i=N} p_i L_i \tag{2}$$

Stimuli

The stimulus set consisted of 45 frequencies in each of the four bands at each of six intensities (total = 1080). Each frequency at each intensity was defined as stable or unstable and as single or a member of a doublet. Lines in a doublet were defined as higher intensity or lower intensity. In some cases, both signals in a doublet would have the same intensity. In order to allow for a margin of error in identifying signals, it was not possible to determine precisely which member of a doublet had been clicked on. Thus, the first time a subject clicked on a doublet, it was assumed that the higher intensity member of the pair had been clicked on and the second time it was assumed that the lower intensity member had been clicked on. A stable signal appeared as straight line 1 pixel wide and 112 pixels in length. An unstable signal appeared as a zig zag line 4 pixels wide on the two lower frequency bands and two pixels wide on the two higher frequency bands. Single line signals were defined as signals that were more than 2 Hz from another signal on the top three bands and

[2]Since the lowest value that the colorimeter displayed was 0.01 cd/m^2, luminances below that level could not be measured. An initial calibration with an EG&G spectroradiometer indicated that the background (and hence level 1) luminances of both monitors were around 0.001 cd/m^2.

3 Hz from another signal on the highest frequency band. Doublets were two signal lines (both either stable or unstable) 1 Hz apart on the three low frequency bands and 2 Hz apart on the high frequency band. This meant that doublets were separated by three pixels on the upper two bands and one pixel on the lower two bands[3].

The stimulus set was randomly ordered and then ten percent of the signals were randomly selected to be unstable signals and twenty percent were randomly selected to be one member of a doublet. The other half of the doublet was generated by selecting a second frequency at the appropriate separation above or below the first and randomly selecting an intensity for it. This randomized set was then divided into six runs of thirty trials, with each trial having six signals from the original stimulus set.

The intensities of the signals were determined using equation 1 with p values greater than 0.5. As the p value increases from 0.5 to 1, the distribution of luminances will be skewed increasingly towards the higher levels and hence a set of pixels (a signal line) will be increasingly discriminable from a background noise with a p of 0.5. Based on pilot tests, a set of probability distributions or p values were selected that would result in signals whose detectability ranged from less than 10% to close to 100%. A slightly higher range was used for the training runs to provide subjects with more examples of signals during the training runs. Table 2 shows the p values used in the training runs and the test runs along with their mean luminances. The corresponding signal intensities in dB are also shown. Since the p values represent the cumulative probability of the normal distribution, the signal intensity for each p value in dB is $20\times\log10$ of the z value that corresponds to that probability.

Table 2: Probability distribution, strength and mean luminance of each signal used in training and test sessions

Training						
Probability (p)	0.62	0.65	0.67	0.69	0.71	0.74
Signal Level (dB)	-10.46	-8.18	-7.13	-6.02	-5.51	-3.81
Mean luminance (cd/m^2)	4.13	5.17	5.97	6.87	7.89	9.66
Testing						
Probability (p)	0.60	0.63	0.65	0.67	0.69	0.72
Signal level (dB)	-12.04	-9.63	-8.18	-7.13	-6.02	-4.73
Mean luminance (cd/m^2)	3.57	4.46	5.17	5.97	6.87	8.42

Conditions

Two experiments were carried out. The first compared detection performance on a monochrome and multichrome monitor and the second experiment compared detection performance under three combinations of monitor and display orientation. These were standard, monitor rotated, and display rotated. All three conditions were run on the

[3]Because of a limitation in the simulation, signals on the display had to be at least 1 Hz apart.

monochrome monitor. The monochrome/multichrome experiment was a within subject design. Six subjects completed both conditions. Three started on the multichrome monitor and three on the monochrome.

The orientation experiment was a between subject design. A different set of six subjects ran in each of the three conditions. The subjects that ran in the monitor rotated and the display rotated conditions did a second set of runs on the other rotation to determine if there was any effect on detection of going from one orientation to the other. Three of the subjects in the standard format condition on the monochrome monitor did their second set of runs on the multichrome monitor and two of the remaining three did their second set of runs on the display rotated condition. The remaining subject did not do a second set of runs.

Task

The task was to detect signals appearing on the FTI display. On each trial, between six and ten signals were presented. The subjects indicated the location of each signal by using a mouse to position the line cursor on top of what they perceived to be a signal and then pressing the left mouse button. They were allowed a leeway on either side of the signals of ±1 Hz on the three lower frequency bands and ±2 Hz on the highest frequency band. Subjects were informed that they were not expected to detect all the signals and that they were to maximize correct detections while minimizing missed signals and false alarms. When the subjects felt they had detected all the signals that they could see on that particular trial, they press 'F1' to advance to the next trial. When all trials for a specific run had been completed the message 'TRIAL LIMIT REACHED SESSION HAS ENDED' was presented.

Procedure

Before giving informed consent, participants read a protocol that provided some background on the purpose of the study, an explanation of the task, the experimental conditions, and the risks. Once consent had been given, subjects were administered a visual acuity test, using a Regan chart at a distance of 6.1 m, and a contrast sensitivity test, using a two alternative forced choice task controlled by a Nicolet Optronics CS2000 Contrast Sensitivity System. Since the task involved the detection of near threshold signals, we wanted to be certain that subjects had normal contrast sensitivity as well as normal or corrected to normal visual acuity.

Observers participated in five sessions - one training session followed by four test sessions. Sessions lasted approximately one and a half hours including breaks and were carried out on separate days. During the runs, subjects were seated in an adjustable chair at a distance of approximately 53 cm from the screen in a dimly lit room. Other than the screen itself, the only illumination was from an incandescent pot light located above the monitor. The light was adjusted so that 0.5 lx fell on the screen and 3 lx fell on the keyboard[4]. The task was carried out under low ambient illumination to maximize contrast on the screen.

At the start of the training session, the task was demonstrated to the subjects and they were given a chance to practice it. They were told that between 6 and 10 signal lines would

[4]All ambient lighting conditions were measured with a Hagner Universal Photometer in the illumination mode.

be presented on each trial, that they had a leeway of ± 1 Hz in clicking on a line, and that they should identify both members of a doublet.

After the demonstration, subjects completed three training runs. On the first training run, subjects were given a list stating the frequency, stability (stable or unstable), and intensity of each signal presented on each trial of that run. With this information, subjects could see what different types and intensities of signals looked like and what percentage of the signals they were likely to see on a trial. On all three training runs feedback was provided in the form of a beep after each correct detection. The first run was 15 trials and the other two runs were 30 trials.

Before each subject moved on to the test portion of the experiment, a brief analysis was done to check if the range of test signal strengths was reasonable. The set of test signal strengths was used for all but one observer who was tested with the training signal levels.

Following training, subjects completed four test sessions of three runs each. Each subject completed the same set of six test runs twice, once for each condition they participated in. The order that the six runs were presented in was randomized for each condition and subject. On the first day of testing, subjects started with a ten trial warm-up run. The procedure was similar to that followed during training except that no feedback was given.

RESULTS

Dependent measures

The overall percentage of correct detections was calculated for each type of stable and unstable signal. As well, the false alarms per trial, the responses per hit and the response times per trial for the first and the last response were determined. Next, the percentage of correct hits at each signal strength was calculated and percent correct as a function of signal strength determined using the Probit routine in SAS®(10). These functions were calculated for all signal types combined and separately for single, higher intensity doublet, and lower intensity doublet lines. From this analysis, the intensities at which the subjects detected 25%, 50%, and 75% of the signals were determined. This latter analysis was carried out on the stable line signals only. There was an insufficient number of unstable line signals to carry out a similar analysis on them. Thus, we could not determine if performance was similar across the two types of lines and it was decided not to combine the data from these signals with the data from stable lines.

General results

Table 3 shows the hit rate for each type of stable line signal as well as the overall hit rate for stable and unstable line signals, responses per hit, false alarms per trial, and average time per trial to first and last response for each condition. The results for the second set of runs carried out by the display and monitor rotated groups are reported separately to show the impact of changing from a display in which time is presented along the y axis to one in which time is presented along the x axis and vice versa. An analysis of variance was carried out to determine if there were any differences in performance between those who ran on one of the rotated conditions first and those who ran on that condition second. No significant differences were found. Thus, the data from all the subjects participating in each

condition (standard, monitor rotated, and display rotated) were used in making comparisons amongst the three orientations.

As can be seen in Table 3, the number of responses per hit was very close to unity. This indicates that subjects did not adopt a strategy of double clicking on signals to ensure that they did not miss any doublets. Similarly, the number of false alarms was very low usually around one per trial. The slight increase for the display rotated group one was due to a single subject. The two response time measures and the hit rate for unstable line signals were also relatively consistent across subjects with the small variation shown being due to individual differences in carrying out the task. An analysis of variance carried out on these measures showed no significant differences in false alarms per trial, responses per hit, response times, and hit rate for unstable lines across the different conditions. Thus, any differences in hit rate should be attributable to differences amongst the conditions under study rather than to differences in the strategy used.

Table 3: Performance measures averaged across all signal strengths for each condition.

Performance Measures	Conditions						
	mono-chrome	multi-chrome	standard display	monitor rotated 1	monitor rotated 2	display rotated 1	display rotated 2
% hits stable	53	53	53	57	58	59	57
% hits unstable	52	49	43	50	43	39	45
% hits S T0	54	53	55	57	57	59	56
% hits S T1	73	74	72	76	80	78	76
% hits S T2	29	32	30	39	39	44	41
Responses/hit	1.04	1.04	1.04	1.04	1.03	1.03	1.03
False alarms	1.04	1.0	1.1	1.2	1.3	2.1	.67
Time first hit	4.1	4.6	5.1	7.0	5.2	6.4	5.8
Time last hit	20.3	20.9	24.9	31.7	21.4	26.8	24.7

S = stable; T0 = single lines; T1 = higher intensity doublet lines; T2 = lower intensity doublet lines.

Monochrome versus multichrome

Figure 2 shows the average signal strength leading to 25%, 50%, and 75% hit rates in the multichrome and monochrome standard conditions for each type of stable line signal. Performance was essentially identical on the two types of monitors for all types of signals. An analysis of variance indicated no significant differences between the two monitors in signal strengths leading to 25%, 50% and 75% hit rates. Similarly, the differences in hit rate between the two monitors, shown in Table 3, were not significant.

Monitor and display orientation

In this experiment, a separate group of six subjects was run in each condition. Subjects then completed a second set of runs on a different condition. As shown in Table 3, overall hit rate appears to be slightly better in the monitor and display rotated conditions

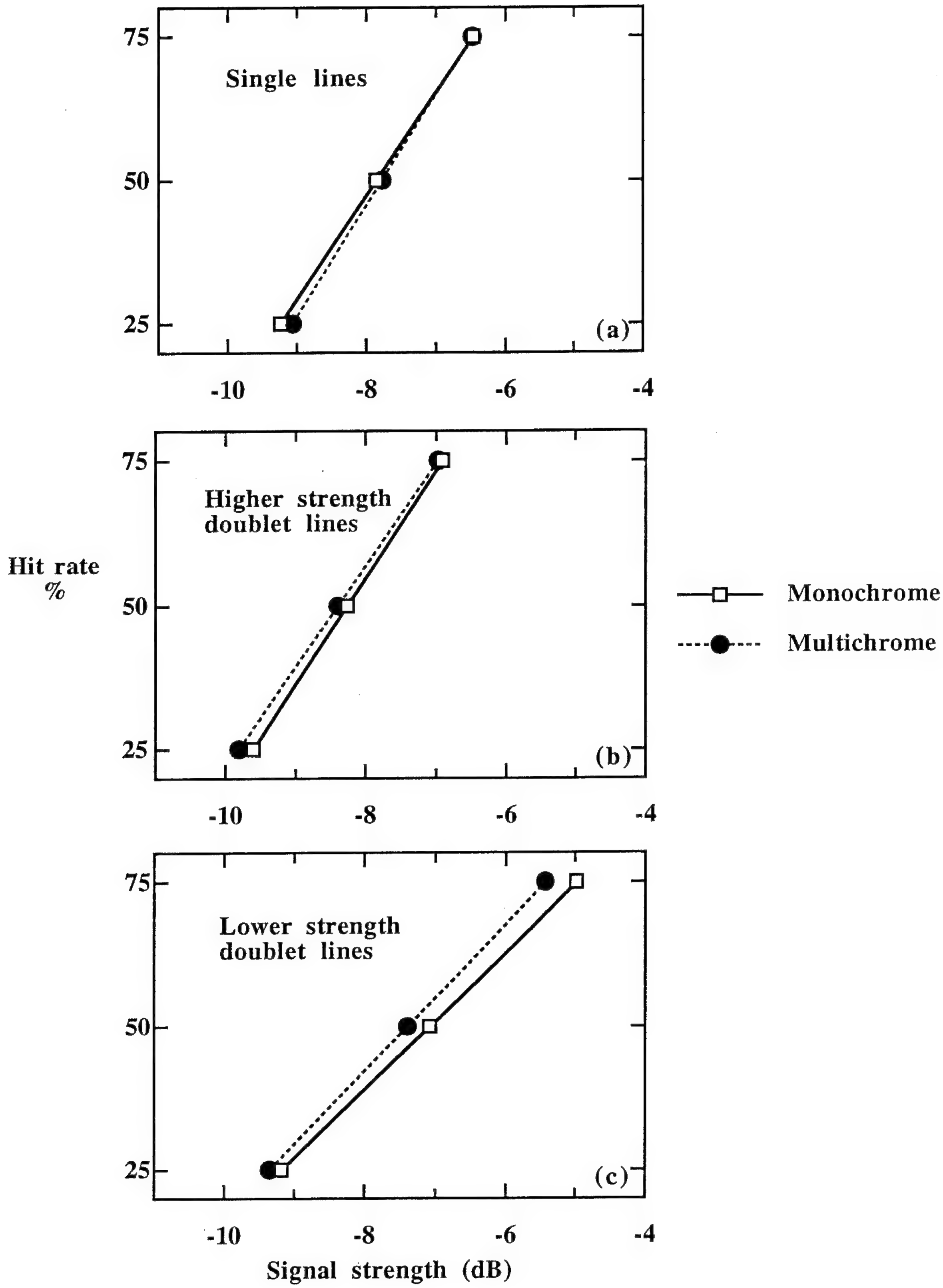

Figure 2: Average signal strength leading to 25%, 50%, and 75% hit rates for (a) single lines, (b) higher strength doublet lines, and (c) lower strength doublet lines.

than in the standard condition for stable line signals. However, a repeated measures analysis of variance, indicated that the only significant difference in performance was percent hits for lower intensity members of stable doublet lines ($F(2,31) = 12.32$, $p=0.01$).

The picture changed somewhat when performance was examined as a function of signal strength. Figure 3 shows the average signal strength leading to 25%, 50%, and 75% hit rate in the standard condition, display rotated condition and monitor rotated condition averaged across all types of stable line signals. At the highest detection rate, there was about one dB difference between the standard condition and the two rotated conditions when all signal types are taken together. This dropped to half a dB at the lower detection rates. Figure 4 shows the same data separated by signal type. The largest effect was found with the lower intensity doublet lines where there was about one dB difference between the standard condition and the rotated conditions at the lowest hit rate. This increased to about 2 dB at the highest hit rate. However, the improvement in the detectability of single and higher intensity doublet lines was much smaller - about a half dB at best.

An analysis of variance, carried out on the differences in signal strength leading to 25%, 50% and 75% hit rates, supported the observed differences in Figures 3 and 4. When the data were collapsed across signal type, a significant difference was found at the 50% ($F(2,32) = 4.06$, $p < 0.05$) and 75% hit rate ($F(2,32) = 5.59$, $p < 0.01$). When the three type of signals were analysed separately, a significant difference was found for the higher intensity doublet lines at the 75% hit rate ($F(2,32) = 5.2$, $p <.05$) and for the lower intensity doublet lines at all three hit rates ($F(2,32) = 10.2$, $p < 0.01$ at 25% hit rate; $F(2,32) = 21.2$, $p <0.01$ at 50% hit rate, and $F(2,32) = 23.5$, $p < 0.01$ at 75% hit rate). Pairwise comparisons of the three conditions, using a Bonferoni T test, indicated that these significance differences were due to a difference in signal strength between the standard display and the two rotated displays. There were no significant differences in signal strength between the monitor rotated and display rotated conditions at any of the hit rates with any of the signal types.

As stated in the method, doublet lines were separated by three pixels in the two lower frequency FTI bands and by 1 pixel in the two higher frequency FTI bands. To see if this difference in separation had any impact, the data for these two sets of bands were analysed separately. Only with the lower intensity doublet lines was there a difference in performance between the two lower and the two higher frequency bands. This difference can be seen in Figure 5. On the lower intensity bands the differences in signal strength between the standard format and the display rotated format are closer to the differences found for single lines and higher intensity doublet lines (Figure 4a and b). With the higher frequency bands, the lower intensity doublet lines are approximately 1.5 to 3 dB more detectable on the rotated displays compared to the standard format. These observed differences were confirmed by an analysis of variance which found a significant difference in signal strength at the 25%, 50% and 75% hit rates ($p < 0.01$) across the three orientations only with data from the higher frequency bands. The differences in signal strength were not significant on the lower frequency bands.

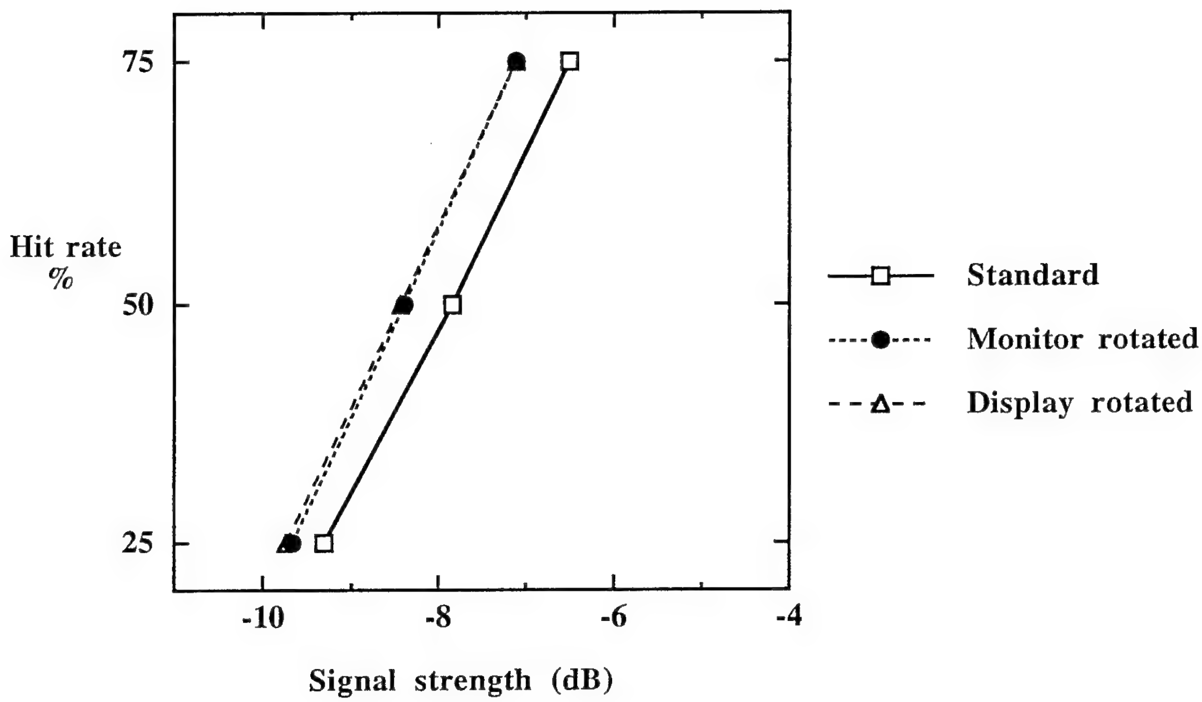

Figure 3: Average signal strength leading to 25%, 50%, and 75% hit rates for the three display formats. Data have been averaged across all signal types and subjects.

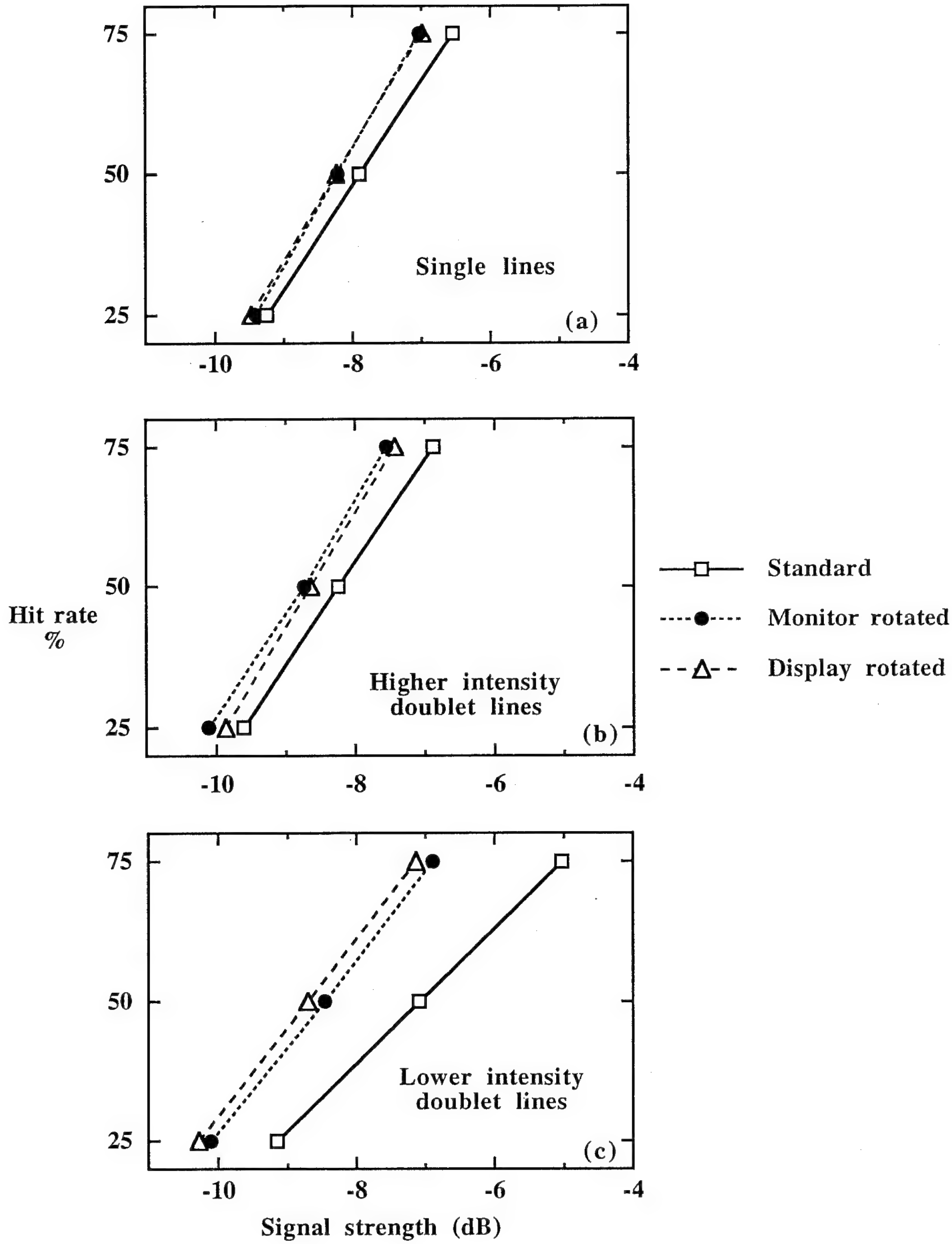

Figure 4: Average signal strength leading to 25%, 50%, and 75% hit rates for (a) single lines, (b) higher intensity doublet lines, and (c) lower intensity doublet lines on the three formats.

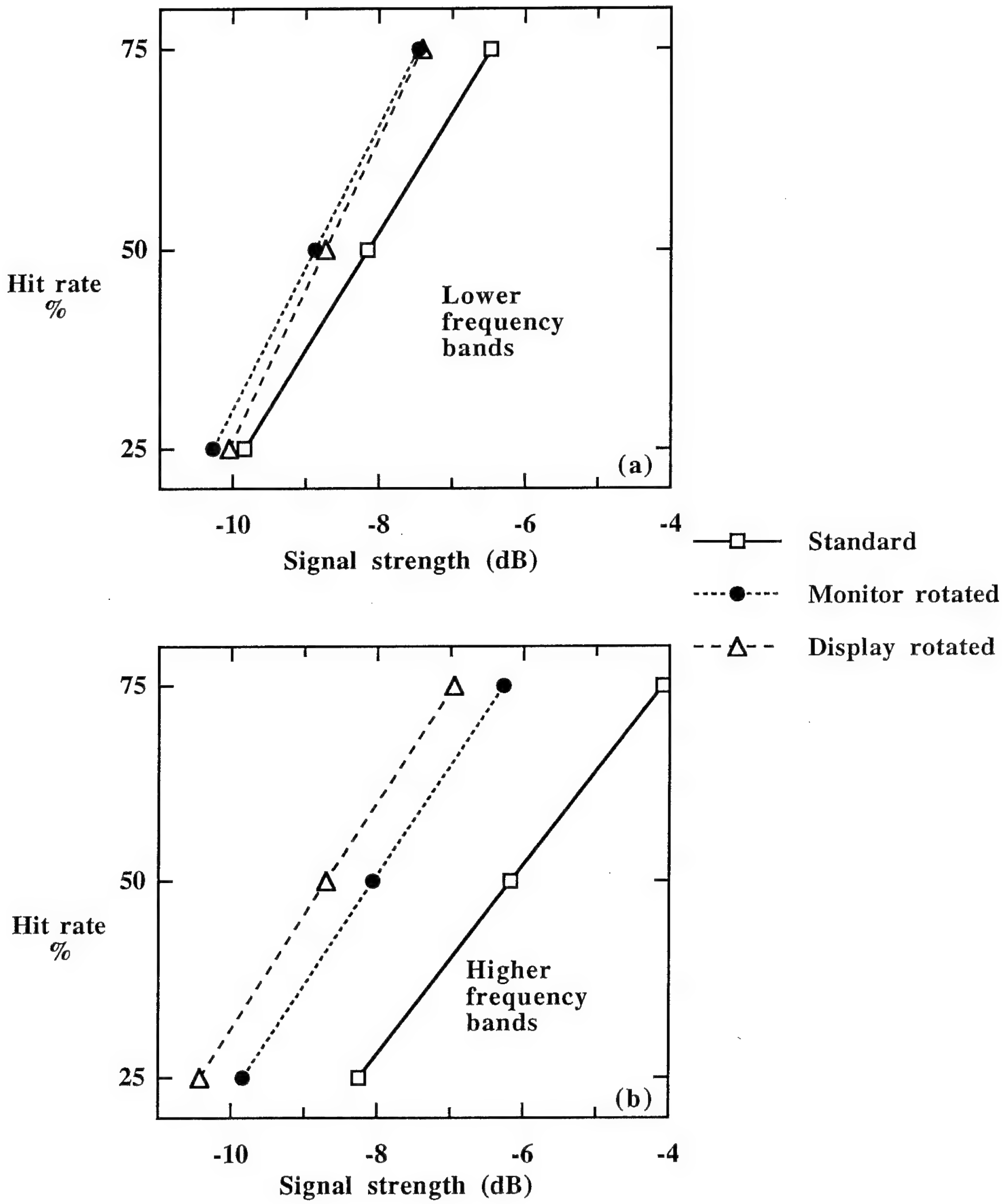

Figure 5: Average signal strength leading to 25%, 50%, and 75% hit rate for lower intensity doublet lines in the (a) lower and (b) higher frequency bands.

DISCUSSION

Monochrome versus multichrome

The purpose of these studies was to examine the effect of monitor type and display orientation on the detection of lines on a simulated sonar display. The study on display type compared performance on a multichrome monitor with that on a single phosphor greyscale monitor. Performance was almost identical on all measures of performance and for all types of lines. This finding supports that of Volkov(8) who found no significant differences in the detection of signals on FTI displays presented on a multichrome CRT and a green, single phosphor monitor. Thus, it would appear that a multichrome display can be used to present FTI displays without a loss in detectability of signals. One remaining question is to what extent these result can be extended to the CANTASS monitor and an equivalent multichrome monitor. The addressability of the monitors in this study were 1024 pixels by 768 lines. This is not far above the minimum addressability required to achieve a resolution to addressability ratio of 1 on a 19 inch display with a 0.31 mask pitch(7) even if the resolution is substantially lower than 1.1 times the mask pitch. If the addressability was increased to 1536 by 1280 (the addressability of the CANTASS monitor) the RAR could be substantially larger unless the resolution was close to the minimum possible or a finer mask pitch was used.

RAR affects the ability to discriminate a line from its background. If the pixels are overlapping then the luminance of one column of pixels affects the luminance of the pixels on either side. This lowers contrast and hence detection threshold. Thus, one might expect differences between a multichrome and monochrome monitor if the addressability of both monitors was higher, providing performance was being limited by the RAR. However, there are several reasons why this is not likely to be the case. Assuming an RAR of 1, the width of a signal line on the monitors in this experiment was about 2.3 minutes of arc at the viewing distance of 53 cm. This translates to a spatial frequency of about 12 cycles per degree. With an addressability of 1536 by 1280, the line width is about 1 to 1.7 minute of arc at a viewing distance of 46 cm or a spatial frequency of 17 to 30 cycles per degree. Detection threshold increases rapidly as spatial frequency increases beyond 12 cpd. Thus, one would expect the detection threshold on the monochrome monitor to increase as addressability increased as well.

There is another factor that may limit detection threshold above that imposed by the RAR; namely, the number of alternative locations in which a signal may appear(11). The larger the number of alternatives, the higher the signal to noise ratio that a signal will be detected at. In this task, as well as in the real task, the number of alternative signal locations is very large. By the time a signal has a sufficient intensity to be discriminated reliably from non signal events, the impact of display RAR may be minimal.

RAR also impacts on the user's ability to see two lines separated by a single row of pixels as unique. As the monitor's RAR increases beyond one, a line pair may be seen as a single, wider line at a slightly lower intensity. Since, detection threshold decreases as spatial frequency decreases (as a line get wider), this single wide line may be more detectable than either member of the line pair by itself. Our results support this hypothesis. The line pairs (as measured by the detectability of the higher intensity member) were more detectable than the single lines. Moreover, subjects stated that their basis for identifying a doublet was the

presence of a slightly broader line especially with the multichrome monitor. Thus, while a high RAR may inherently impair the discriminability of line pairs, its effect in practice may be minimal. In a real sonar task, the presence of a broader line would not necessarily mean a line pair. However, it would probably cue the operator to look at that frequency range on a higher frequency resolution FTI display.

Monitor and display orientation

The study on display orientation compared the detectability of lines and line pairs when the FTI display and/or the monitor were configured so that signals fell either along the scan lines of a single phosphor CRT or perpendicular to them. As indicated by Figures 3, and 4 and Table 3 there was some advantage to having signals fall along the CRT scan lines. The pattern of results suggests that it is the visibility of the lines that is being improved. Below threshold lines are not becoming visible, but moderately detectable lines are being detected more consistently. The exception was with doublet lines that were separated by one pixel. When these lines fell along the scan lines of the CRT, detectability improved at all signal intensities.

This finding of increased visibility would suggest that signal lines might be detected sooner or that detection would be improved under time pressure. In this study, there were no differences in response times across the different conditions. However, time was not limited and there was usually a relatively high intensity signal that could be detected easily on either format. These factors could have masked potential differences in response time. With the real system, signal lines appear over time and often do not extend the full length of the FTI display. In order to process all of the incoming data, operators must scan each display relatively quickly. Thus, greater improvements in performance might be expected with a real system than were found in this study.

The most important improvement was that the detectability of the lower intensity member of a line pair improved significantly in both the rotated conditions. Doublets can be indicative of particular types of targets. More importantly, they may indicate a second target hiding in the shadow of a noisier vessel. Thus reorienting either the display and/or the monitor would seem to offer a significant improvement on a critical detection task.

Both methods of modifying the display so that signal lines fell along the scan lines produced similar levels of improvement. Moreover, subjects had no difficulty in switching from time displayed along the y axis to time along the x axis and vice versa. However, none of the subjects had extensive experience with one mode over the other and the detection task did not involve pattern recognition. Reversing the axes of the FTI display may interfere substantially with the classification performance and possibly even the detection performance of experienced operators. Changing the orientation of the monitors would require extensive modifications to the alphanumeric portions of the display, and probably necessitate a complete redesign of the CANTASS display screens. Thus, further study is required to determine the impact of reorienting the display and monitor.

Limitations of the study

The methodology for this study was chosen to allow the collection of a reasonable quantity of data, relatively quickly, under conditions that were both realistic and yet controlled. The latter improves the likelihood that any differences between conditions will not be masked by excessive variance. Thus, subjects received a fixed number of signals over a fixed number of trials and were usually presented with a range of signal intensities on each trial. These conditions help keep the subject alert, keep false alarm rate low, and keep hit rate consistent since subjects are constantly reminded about what constitutes a signal and non-signal. In the real task, an operator monitors a display over an extended period of time. New signals appear at random intervals and slowly extend over the length of the display. Under these conditions, the subject may have difficulty staying alert and false alarm and hit rate may be more variable. Under such conditions, improving the visibility of lines could lead to larger improvements in detection than were found with the method used in this study.

On the other hand, anything that could degrade performance over time is likely to have a negative impact on the real task. For example, the higher RAR on a multichrome CRT may make lines and text appear slightly blurry. This could lead to the multichrome monitor being more fatiguing over time than the monochrome monitor. In this study, subjects often completed a run of thirty trials in 10 minutes. However, some subjects took considerably longer. As well, subjects often completed three runs with only short breaks between runs. There was no evidence that performance was poorer on the third run than the first on either monitor nor did subjects indicate a preference for one monitor over the other.

This study only looked at the benefit of having signal lines fall along the scan lines of the CRT for a single phosphor monitor. The same advantage may not be found with a multichrome monitor because of the shadow mask. Before a decision is made to go to a multichrome monitor, a further study is required to investigate the impact of having signal lines fall along the scan lines of a multichrome monitor.

CONCLUSIONS

Two experiments were carried out to examine the detectability of signals on an FTI display on a monochrome and multichrome monitor and under three different combinations of monitor and display orientation. There were no differences in detectability of signals on the two types of monitors. Detection of some types of signal lines improved significantly when the monitor or the FTI display was oriented so that the signal lines fell along the scan lines of the CRT. Based on the results of the first experiment and related studies, the use of multichrome monitors is not like to degrade detection of lines on FTI displays and should not be avoided in passive sonar systems on that basis. The decision to include multichrome monitors should be made on other issues such as usefulness, compatibility with other equipment, stability, and reliability. This study did not address any of those issues. Based on the results of the second experiment, there could be considerable benefit to modifying passive sonar systems so that signal lines fall along the scan lines of the CRT. However, further study is required to see if similar results are found on a multichrome CRT and and if the results hold up under more realistic test conditions and with experienced operators.

RECOMMENDATIONS

1) The advantages of using multichrome monitors for displaying passive sonar should be investigated.

2) Further studies should be conducted to assess more fully the potential benefit of modifying the orientation of the FTI display or rotating the monitor in a passive sonar system so that signal lines fall along the scan lines of the CRT. Potential studies include measuring performance on a rotated display on a multichrome monitor and measuring performance on the different display formats under more realistic test conditions.

3) If the results of the additional studies support the current findings, a field study should be run to assess the impact of reorienting the FTI display on the performance of actual operators.

ACKNOWLEDGEMENTS

The research reported in this paper was supported under a tasking to DCIEM, DMCS 187, from DMCS 3. The idea for the experiment on display orientation was originally suggested by LCDR Paul Delhaise, DMCS 3.

REFERENCES

1. *CANTASS Human Factors Study*. DMCS 187, DGMEM/DMCS 3, NDHQ, Ottawa, Canada, 1993.
2. MOULDEN, B. and F. KINGDOM. Effect of pixel height, display height, and vertical resolution on the detection of a simple vertical line in visual noise. *Human Factors*. **29**: 433-445, 1987.
3. MOULDEN, B. and F. KINGDOM. Effect of pixel width, display width, and number of alternative signal locations on the detection of a simple vertical-line signal in visual noise. *Perception & Psychophysics*. **43**: 592-598, 1988.
4. MCFADDEN, S. M., M. M. TAYLOR, and C. D. FAST. *Detection of simulated sonar line targets in frequency-time-intensity displays with reduced display area*. DCIEM No. 83-R-56, Defence and Civil Institute of Environmental Medicine, Downsview, Ontario, 1983.
5. MCFADDEN, S. M. and K. SWANSTON. Mapping of amplitude onto CRT luminance in frequency-time-intensity displays. *Proceedings of the Human Factors Society 30th Annual Meeting*. **1**: 164-167, 1986.
6. MOULDEN, B. and F. KINGDOM. Effect of the number of grey levels on the detectability of a simple line signal in visual noise. *Spatial Vision*. **2**: 61-77, 1987.
7. MURCH, G., L. VIRGIN, and R. BEATON. Resolution and addressability: How much is enough. *Proceedings of the Society for Information Display*. **26**: 305-308, 1985.

8. VOLKOV JR., G. Effects of shadow mask color vs. monochrome CRTs on detection of sonar signals. *Society for Information Display 85 Digest of Technical Papers*, 111-114, 1985.

9. MCFADDEN, S. M. Discrimination of colours presented against different coloured backgrounds. *Color Res. Appl.* **17**: 339-351, 1992.

10. SAS INSTITUTE INC. *SAS® technical report P-179, additional SAS/STAT™ procedures, release 6.03*. SAS Institute Inc., Cary, NC, 1988.

11. MACMILLAN, N. A. and C. D. CREELMAN. *Detection theory: A user's guide*. Cambridge University Press, New York, NY, 1991.

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g., Establishment sponsoring a contractor's report, or tasking agency, are entered in section 12.) Defence and Civil Institute of Environmental Medicine 1133 Sheppard Ave. W., P.O. Box 2000, North York, Ont. M3M 3B9	2. DOCUMENT SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable.) Unclassified/Unlimited

3. DOCUMENT TITLE (the complete document title as indicated on the title page. Its classification should be indicated be the appropriate abbreviation (S,C,R or U) in parentheses after the title.)
The effect of monitor type and display orientation on the detection of lines on a simulated passive sonar display

4. DESCRIPTIVE NOTES (the category of the document, e.g., technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical report

5. AUTHOR(S) (Last name, first name, middle initial. If military, show rank, e.g., Burns, Maj. Frank E.)
McFadden, Sharon, M. Giesbrecht, Barry, L., Kalmbach, Karen, C.

6. DOCUMENT DATE (month and year of publication of document) October 1995	7.a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.) 21	7.b. NO. OF REFS. (total cited in document) 11

8.a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)	8.b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)
9.a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by with the document is identified by the originating activity. This number must be unique to this document.) DCIEM No. 95-32	9.b. OTHER DOCUMENT NO.(S) (any other numbers which may be assigned this document either by the originator or by the sponsor.)

10. DOCUMENT AVAILABILITY (any limitation on further dissemination of the document, other than those imposed by security classification)

X	Unlimited distribution
	Distribution limited to defence departments and defence contractors; further distribution only as approved
	Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
	Distribution limited to government departments and agencies; further distribution only as approved
	Distribution limited to defence departments; further distribution only as approved
	Other

11. ANNOUNCEMENT AVAILABILITY (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (10.) However, where further distribution (beyond the audience specified in 10) is possible, a wider announcement audience may be selected.)
Unlimited

12. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)
DMCS

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

With current sonar technology the operator must handle large quantities of data. The primary medium for displaying this data is the CRT. Because of the limited space available on the CRT, the operator must scan multiple pages of data rapidly if he or she is to monitor all of the information. Thus, signal visibility is critical. To ensure good visibility, it is necessary to understand the impact of display characteristics on the detectability of signals on a display. This study examined two factors that could influence the detection of lines on a frequency-time-intensity (FTI) display. The first was type of monitor - multichrome or monochrome. Current systems use a monochrome monitor because its resolution is believed to be superior to a multichrome monitor. The second was orientation of the signals relative to the orientation of the CRT raster. Currently, the signals on an FTI display are perpendicular to the CRT raster. The study examined the advantage of having signal lines on the FTI display fall along the scan lines of the CRT. Two experiments were carried out to assess the effect of these factors on the detection of signals of varying strength presented on a simulated FTI display. Performance was similar on the monochrome and multichrome monitors. However, there was a slight advantage, about 1 dB, to using a display format in which the signals fell along the scan lines of the CRT. This improvement increased to 2 dB for signals that were separated by one pixel from a stronger signal. It was concluded that detection was not impaired on a multichrome display and that there could be an advantage to designing the interface for a passive sonar display so that the signals fall along the scan lines of the CRT.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible, keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and the thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

passive sonar
detection
visibility
resolution
scan lines
monochrome monitor
multichrome monitor
display
orientation